BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Potential Lunar Landing Capability of Apollo - Case 340

DATE: August 9, 1967

FROM: C. J. Byrne

ABSTRACT

The potential lunar landing capability of Apollo is considerably in excess of that required for the candidate sites in a number of respects. This paper discusses the reserve potential in accessibility, aim accuracy, landing capability, approach path roughness, and launch opportunities.

The reserve represents an added safety margin for early landings and a source of growth capability in later landings.

The material upon which this memorandum is based is taken from previous MSC and Bellcomm, Inc. studies. It was gathered in response to a request from the Science and Technology Advisory Committee.

[redacted]

(NASA-CR-154901) POTENTIAL LUNAR LANDING CAPABILITY OF APOLLO (Bellcomm, Inc.) 11 p

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MEMORANDUM FOR FILE

I. INTRODUCTION

When the performance specifications on Apollo were set, there were a number of unknown factors in the lunar environment, in the ultimate weight and propulsion budgets of the spacecraft, in the state of the art of lunar landings, and in the reliability of the systems. Consequently, a great deal of conservatism was written into the specifications.

At the present time, many of these unknowns are being resolved, particularly those relating to the lunar environment and lunar landings. As a result, it would be possible to tighten the specifications in certain areas if this were necessary; in practice, the costs of verifying tighter specifications will not be incurred unless there is a motive strong enough to compete with critical needs of the program.

On the other hand, in other areas the specified performance has not been met. Where the gap does not jeopardize the safety or chance of success of Apollo, no corrective action will be taken.

The purpose of this memorandum is to indicate reserves of ability and areas for future growth. In all cases, potential in excess of specified performance has not been verified by tests and studies to the level of confidence needed for qualification. In some cases, only flight experience with Apollo spacecraft could lead to the confidence necessary to use the potential.

II. ACCESSIBILITY

The region of the moon which is accessible to Apollo is limited by a set of program ground rules, including:

a) free return translunar trajectory

b) budgeted fuel and weight margins [redacted]

c) launch any month

d) earth tracking during descent and ascent

The specified and presently estimated* limits of accessibility are shown in Figure 1.

To illustrate the effect of releasing these ground rules, Figure 2 shows the accessible region for launch one month in the year (allowing landings up to 15° from the equator) and Figure 3 shows the region for non-free return trajectories (allowing landings up to 30° from the equator within 25° of the central meridian and out to the poles along the central meridian). If the requirement for earth tracking during descent and ascent were removed, landings on the limbs and far side of the moon would be possible.

III. AIM ACCURACY

The aim accuracy of Apollo is determined by the total capability of MSN tracking, sightings of lunar landmarks, and redesignation during the LM descent. The specified performance (1/2 nm CEP) has not been met; for a comparable probability level, the area of the landing site has increased by about 50% (Figure 4). However, studies of Lunar Orbiter data show that good landing areas of this size can be found. In all candidate Apollo sites, redesignation is sufficient to avoid all hazardous areas which could be encountered in at least 99.7% of the landings. Although the Apollo redesignation capability is sufficient to remove all navigation errors in most (but not 99%) of the landings, no redesignation will be used for this purpose in early landings in order to save fuel for obstacle avoidance near touchdown.

Up to the present time, Lunar Orbiter experience has not verified the expected accuracy of earth-based lunar orbit determination. It is hoped that this situation will be resolved before Apollo landings. In case problems remain, the tracking data will be supplemented by navigational sightings of lunar landmarks.

IV. LANDING CAPABILITY

Analysis of the LM design shows that landings are safe on a 6° general slope with 24 inch deep craters or 24 inch boulders, for a soil strength of 5.5 psi at the surface, linearly increasing with depth at the rate of 3.6 psi per inch. Specified extreme touchdown velocities of 10 fps vertical and 4 fps horizontal were assumed.

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*Weight growth in the CM may reduce the accessible area below that indicated in Figures 1 and 2. The potential change is being considered in site survey targeting, but the weights are not yet firm enough to justify presenting new accessibility figures here.

Surveyor information indicates stronger soil characteristics and Surveyor and Lunar Orbiter photographs indicate that rocks larger than 24 inches tend to be clustered in avoidable areas. The slopes in mare areas outside craters appear to be much less than 6°. Analysis of the guidance system indicates that the chance of exceeding a 3 fps horizontal velocity is less than 1%; at this velocity, the general slope could be as large as 8°. If the surface is hard and smooth, the slope could be 14°.

As a result, craters of the order of 5 meters or more in diameter appear to be the major hazards. The density of these is such that the astronauts should be able to avoid them easily in guiding the final touchdown. If this confidence is reinforced by pilots' experience during early landings, it should be possible to land on rougher sites than the Apollo candidate sites, possibly including highlands or crater floors.

V. APPROACH PATH ROUGHNESS

Originally, Apollo was to land over an arbitrary approach path. In consideration of the low inclination trajectory dictated by fuel economy, and uncertainties in altitude, it was decided to use radar altimeter data for about 20 miles before touchdown. Because of a desire to set up precise conditions for the visibility phase, the spacecraft is especially sensitive to altitude variations within 10 miles of the aim point. Furthermore, altitude errors cut into the effectiveness of downrange redesignation capability by generating an aiming error. Because of these factors, the approach path has been constrained to fit within the envelope shown in Figure 5.

A number of steps are under consideration to alleviate the problem (Table 1); however, limitations on roughness and slope will almost certainly remain unless major changes in trajectory, hardware and software are made.

VI. LIGHTING, LAUNCH OPPORTUNITIES, AND MULTIPLE SITES

Much of the capability discussed above depends on astronaut detection and avoidance of hazards. This, in turn, presupposes desirable lighting conditions (about 7° to 18° sun elevation).

Launch reliability considerations make it highly desirable to allow for two successive slips of two days each. Since the sun moves at 13° per day, three landing sites are required for each month of launch, at different longitudes across the moon.

As launch experience builds up, it may be possible to target for only one or two opportunities per month. This will be particularly important for the western sites. Use of pre-planned dog-legs can be used to widen the constraint slightly for some sites in some months.

Finally, high latitude sites (above 30°) are not so critical on sun angle because the illumination is not in the trajectory plane.

VII. SUMMARY

There are a number of areas where the Apollo landing capability has been, or may be, shown to be in excess of that required for landing in the set of candidate sites. This capability represents a safety factor in early landings, permitting hold and recycle of the launch vehicle, correction of unexpected navigation errors, and landing in rougher areas than expected.

For later landings, some of this potential can be used for landing to special features of scientific interest, in more difficult approach and landing environments. However, studies and tests to confirm the additional capability must be scheduled.

ACKNOWLEDGEMENTS

The author is grateful to D. B. James for discussions and suggestions contributing to the paper. Figures 1, 2, 4, and 5 and Table 1 were adapted from the MSC presentation to the Apollo Site Selection Board on March 30, 1967. Figure 3 was adapted from work by J. S. Dudek, W. D. Kinney, and K. Smith.*

D B James for CJB

1012-CJB-hjt C. J. Byrne

Attachments:
Figures 1 - 5
Table 1

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*A Study of the Behavior of Lunar Accessibility Over Extended Time Periods, J. S. Dudek, W. D. Kinney, K. Smith, Bellcomm, Inc., TR-65-310-1; October 22, 1965

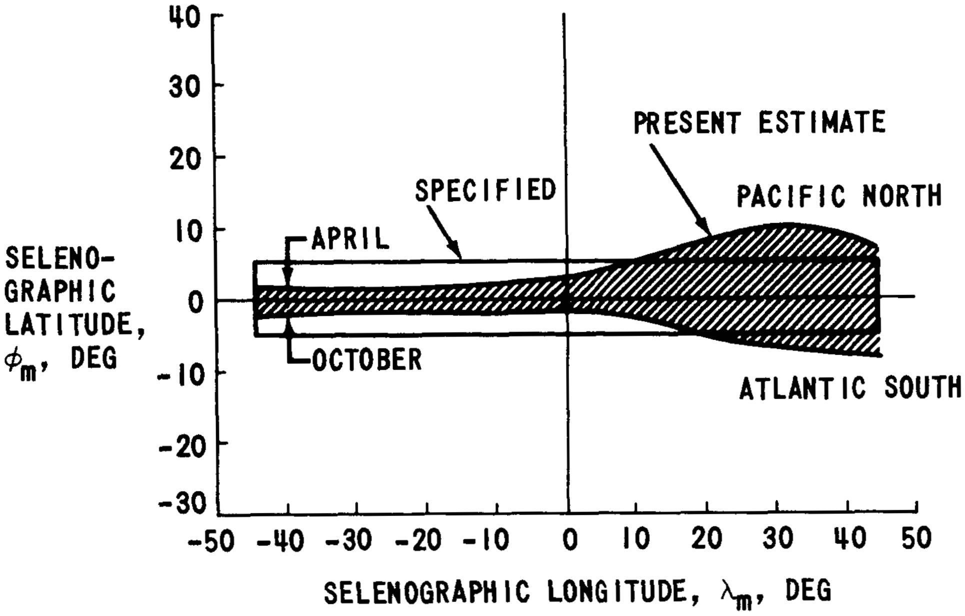


FIGURE 1 - COMBINED ACCESSIBLE AREA

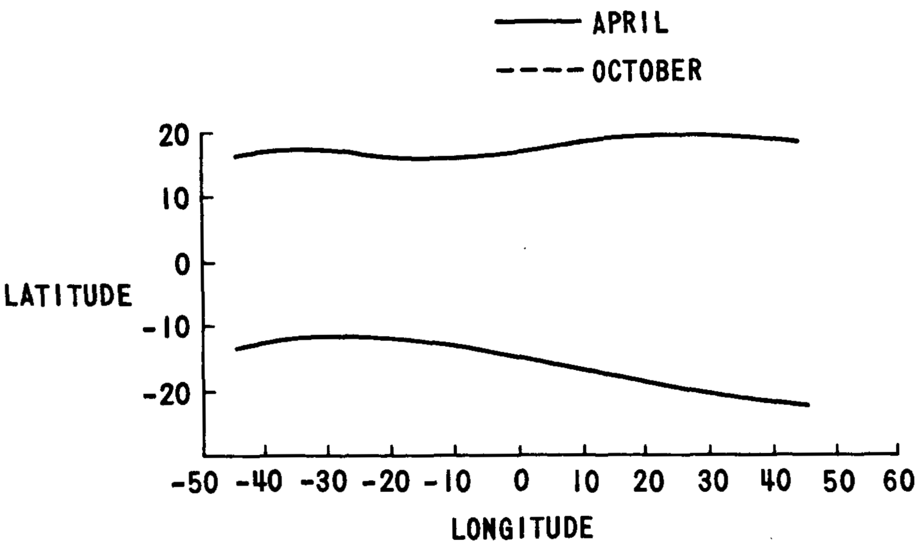


FIGURE 2 - MAXIMUM VARIATION OF ACCESSIBLE
AREA FOR PACIFIC INJECTION

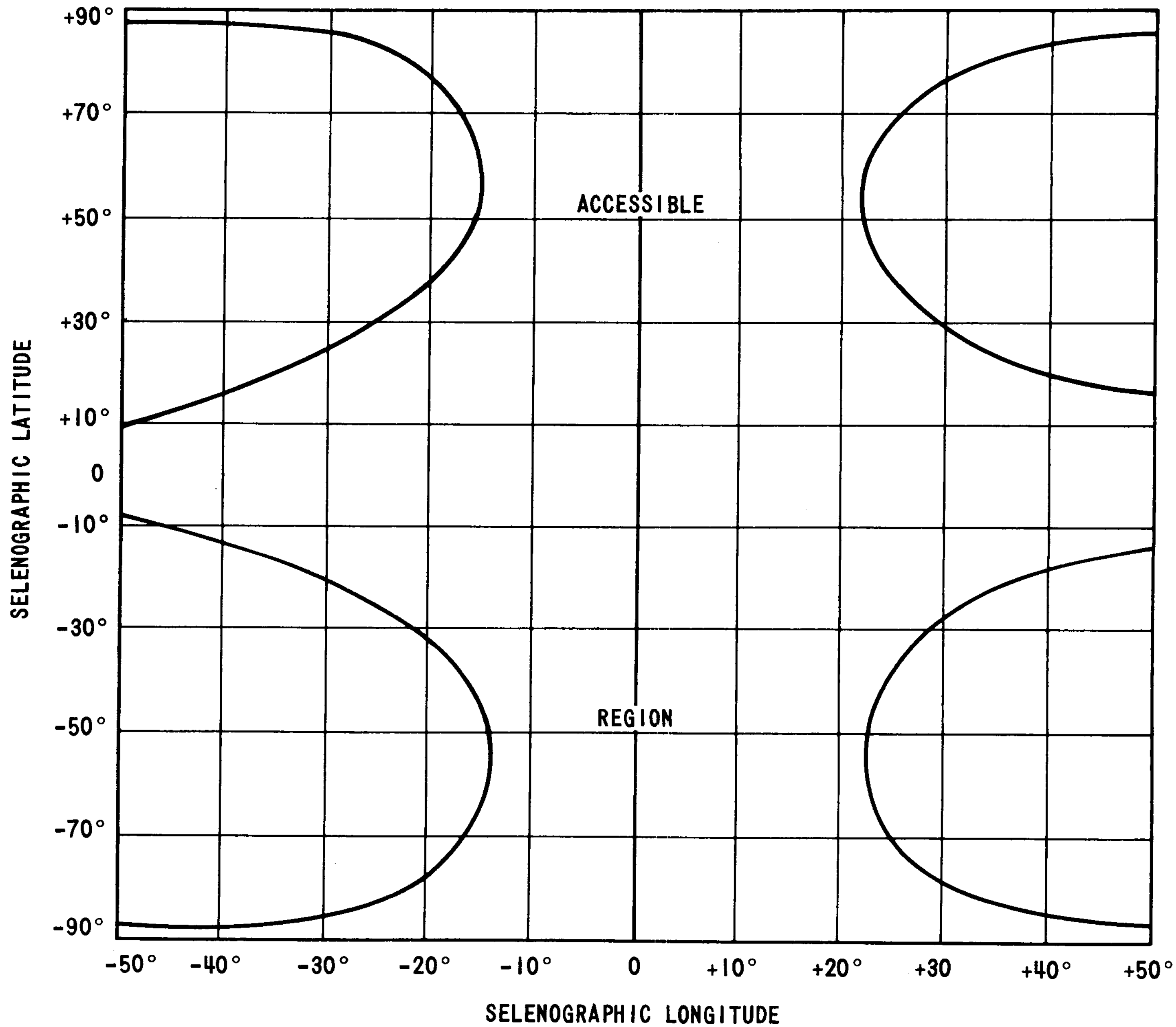
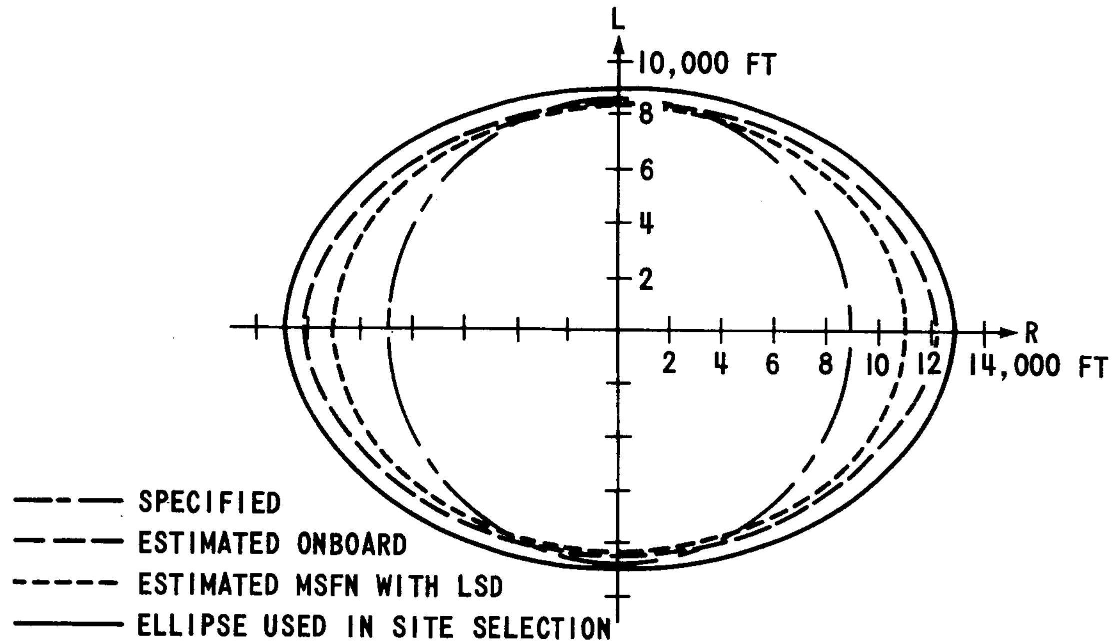


FIGURE 3 - NON-FREE RETURN ACCESSIBILITY FOR THE 20 YEAR PERIOD FROM 1968 TO 1987



PROBABILITY OF LANDING WITHIN ELLIPSE IS 99.7%

FIGURE 4 - LANDING SITE DISPERSION ELLIPSE

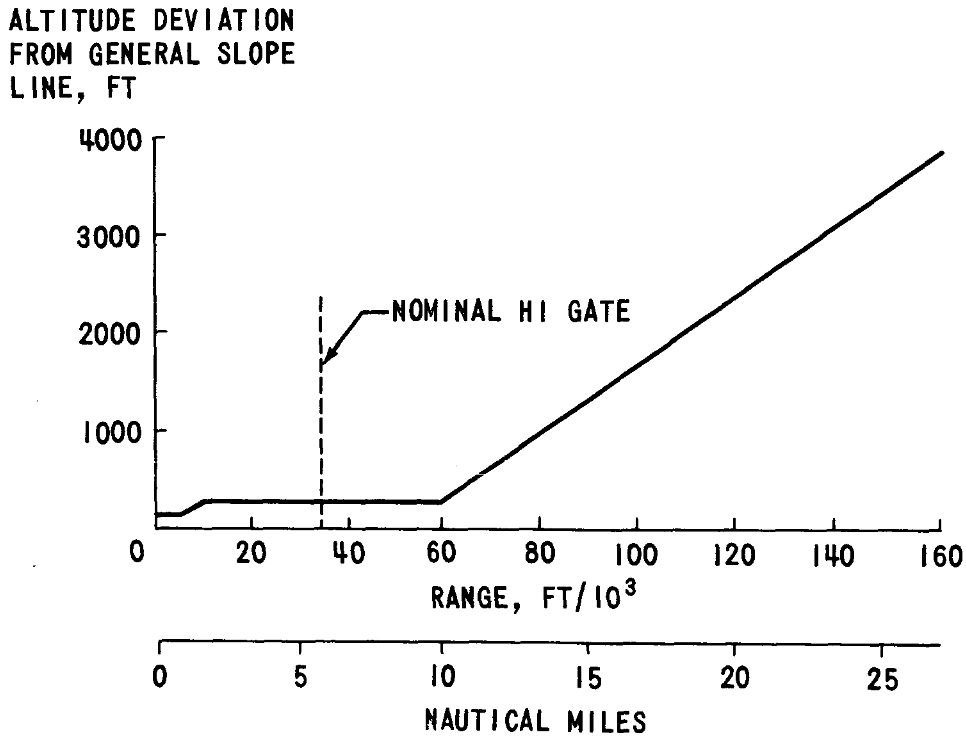


FIGURE 5 - SITE SELECTION TERRAIN CRITERIA
(EXCEPTS GENERAL SLOPE)

TABLE 1

CONTINGENCY AND FUTURE CAPABILITY PLANNING ANALYSIS

Increased Landing Radar Data Processing

- Slope estimation
  - Techniques being examined for effectiveness and software costs
- Different weighting function
- Data smoothing in guidance computer

Guidance Logic Modification

- Modify time for guidance constant freeze
- Limited guidance from constants freeze point to hi-gate
- Different targeting
  - Lower hi-gate
  - Greater visibility margin

Relax Criteria

- Landing radar pitch operating range increase
- Less visibility margin at hi-gate
- Use manual redesignation to improve visibility margin

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